Codes and Standards Enhancement Initiative
For PY2005: Title 20 Standards Development

Response to NEMA Comments of May 24, 2005 on the California Energy Commission's Proposed Energy Efficiency Standards for General Service Incandescent Lamps

Prepared for:

Gary B. Fernstrom, PG&E

PG&E Pacific Gas and Electric Company™

Prepared by:

Chris Calwell, Ecos Consulting

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The National Electrical Manufacturers Association submitted comments to the California Energy Commission on May 24, 2005 primarily on the subject of krypton fill gas for incandescent lamps. NEMA's comments addressed the scarcity, cost premium, efficiency benefits, and economic analysis associated with krypton's use in incandescent lamps. While krypton fill gas represents only one of a number of promising technologies for improving lamp efficacy cost effectively, it is the focus of the NEMA comments and our response, which follows.

Cost and Relative Availability of Krypton Gas

Many of NEMA's comments about the cost of krypton stem from its observations that krypton is less prevalent in the atmosphere than nitrogen, oxygen, or argon. We noted the same finding in our market research. However, krypton can be obtained anywhere in the world by fractionating or condensing air into its constituent components at various temperatures. Krypton is not concentrated only in politically unstable countries nor subject to the political constraints on availability that are characteristic of strategic metals like platinum and palladium and other natural resources like petroleum. Facilities currently exist in the U.S., Europe and Asia for isolating krypton from the atmosphere, making it available where needed by manufacturers of lighting and fenestration products.

Roughly 1 of every million air molecules is krypton. However, the earth's atmosphere consists of some 1.8×10^{20} moles of air molecules, making about 5.8×10^{12} liters of krypton available in the atmosphere or approximately 2.2×10^{10} kg.[1] We estimate that the total volume of krypton needed to comply with proposed CEC standards in California is approximately 3 to 7 million liters per year, or about 0.000086% of the globally available volume. Distilling the amount of krypton available in the column of atmosphere above Sacramento County alone would provide enough krypton to meet the state's total demand for krypton resulting from these standards for a period of *five to six years*.[2]

NEMA has misunderstood or misstated findings from our earlier presentations on the subject of the cost of krypton. NEMA's comments state, "In previous meetings, it was verbally suggested and assumed in the discussions that Krypton is **3 times** (300%) more expensive than argon. In fact, Krypton is more than **300 times** more expensive than Argon. This is the **Second** significant assumption **Error.**"

The slide Ecos Consulting presented at a January 2005 California Energy Commission workshop with NEMA and its members is shown in Figure 1. Based on conversations with Spectra Gases and Air Liquide, Ecos researchers concluded that market prices for krypton currently range from \$0.35 to \$0.65 per liter, compared to a price of \$0.0007 to \$0.001 per liter for argon. On average, then, we assumed that krypton is about 600 times more expensive than argon for an equivalent volume. We welcome NEMA's input that

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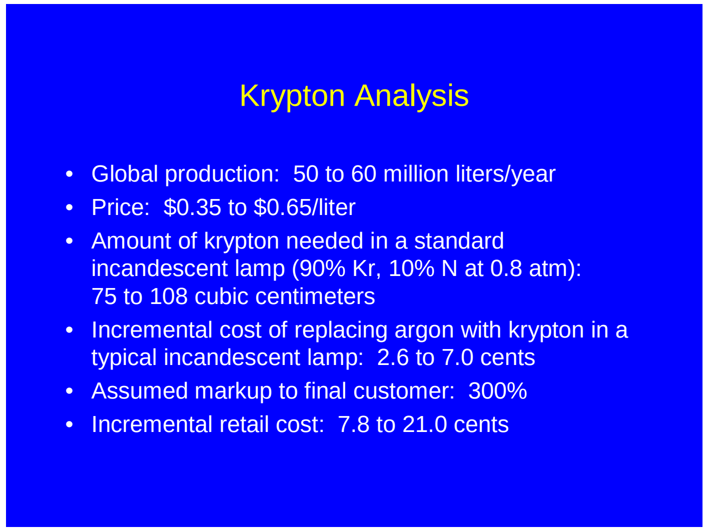
[1] See John Harte, *Consider a Spherical Cow: A Course in Environmental Problem Solving*, University of California at Berkeley, 1985, pp. 232-236; and http://environmentalchemistry.com/yogi/periodic/Kr.html.
[2] Total surface area of the earth is 5.1×10^{14} square meters. 0.000086% of that translates into 170 square miles, compared to Sacramento County's area of 966 square miles.

the actual price premium is closer to a factor of 300, and can revise our cost effectiveness calculations to reflect the new data if NEMA can provide actual purchase data in cents/liter. This would have the effect of slightly reducing our manufacturer incremental cost estimate of 2.6 to 7.0 cents per lamp, as well as reducing the final retail cost increment of 7.8 to 21 cents per lamp (including a generous assumption that the final retail price, after manufacturer and retailer markup, is three times higher.”

Figure 1 - Krypton Analysis Summary



It is these engineering estimates that are the most relevant to determining incremental cost of producing krypton lamps in large volume for sale in conventional bulbs in California. If the lamp shape and size, base type, and filament design remain virtually the same and the only thing that changes is that krypton tanks are connected to the assembly line instead of argon tanks, determining incremental cost is straightforward. It requires answers to two questions: how much fill gas is needed and how much more does krypton cost than argon? All of our assumptions about fill volumes are shown in Figure 1, including measured lamp volume, ratio of krypton to nitrogen, and fill pressure.

By contrast, NEMA asserts that a price of $0.75 to $1.00 is currently being charged at retail in China for niche krypton lamps made in small quantities for specialized applications – suggesting an incremental cost of roughly $0.50 to $0.75. This is an interesting illustration of the effect of profit margins and exchange rates on final retail price in dollars of niche products sold in a foreign market, but not a credible prediction of the cost of making and selling such lamps in annual quantities of tens of millions in the California market.

NEMA also misunderstood the Ecos Consulting/PG&E assertion regarding economies of scale. This was not a reference to krypton becoming less expensive when purchased in quantity. We concur that krypton would tend to have a fairly similar price per liter whether the buyer were purchasing tens of thousands of liters at a time or millions. Rather, we assert that finished lamps become less expensive per unit as advertising, packaging design, and technical research costs become amortized across tens of millions of units.

NEMA further asserts that an additional amount of krypton will necessarily be lost in the manufacturing process, so they believe our analysis underestimates incremental cost.

NEMA has not demonstrated that the incandescent lamp manufacturing process *requires* the venting of substantial volumes of noble gas. Moreover, the market has already anticipated the value of recovering such gases and developed equipment to recover the krypton cost effectively. The initial focus has been on insulated window manufacturers, though the technology is relevant to the lamp manufacturing business as well. Here is one such example from Spectra Gases (www.spectragases.com/specialapplgasmkts/R20Rec.htm):

Figure 2 - Sample Krypton Recovery Equipment from Spectra Gases

We believe that manufacturers would weigh the cost of installing such recovery equipment against the value of krypton recovered and employ the most cost effective approach.

Similarly, NEMA asserted that manufacturers would face substantial additional costs associated with new valves, manifolds, and piping. Since both krypton and argon are noble gases with very similar chemical properties, we are aware of no special requirements for handling one of the gases that would not already be needed to handle the other. Valves would simply need to be calibrated to deliver the desired dose of heavier krypton instead of argon.

Efficiency Benefits of Krypton Gas

NEMA cites the Illuminating Engineering Society of America's *Lighting Handbook: Reference & Application* in its discussion about standardized ways of calculating lighting economics. IESNA's equations for such calculations appear on page 25-1 in the 9th Edition (published in 2000). We commend to NEMA an earlier discussion in the same reference book (page 6-9) of the benefits of krypton fill gas in incandescent lamps:

> Krypton, although expensive, is used in some lamps where the increase in cost is justified by the increased efficacy or increased life. Krypton gas has lower heat conductivity than argon. Also, the krypton molecule is larger than that of argon and therefore further retards the evaporation of the filament. Depending on the filament form, bulb size, and mixture of nitrogen and argon, krypton fill can increase efficacy by 7 to 20%.

Our own estimates of the efficiency benefit of krypton lamps are taken directly from the same two industry research papers cited by the *IESNA Handbook* – both published by Durotest researchers in the early 1970s when krypton lamps were first being commercialized.[3] We subsequently contacted the authors to confirm key details.

Likewise, Osram Sylvania published its own estimate of the efficiency benefits of krypton fill gas in a 1996 Engineering Bulletin entitled "Incandescent Lamp Manufacture." Osram characterizes the benefits of krypton use on page 5 as follows:

> Krypton, which is heavier than but has characteristics similar to argon, is an excellent fill gas. Using krypton produces an increase up to 10% in efficacy (lumens per watt) without a decrease in lamp life. Unfortunately, krypton is considerably more expensive than argon and nitrogen. Some OSRAM SYLVANIA Traffic Signal Lamps utilize krypton since the advantages of krypton more than offset the increased cost.

Similarly, in more recent advertising for its "SuperLux Krypton" lamps, Osram Sylvania claims an efficacy improvement of up to 10% and a number of other non-energy benefits from using krypton fill gas instead of argon:

> **Up to 10 % more light**
> As far as brightness and quality of light are concerned, OSRAM SUPERLUX® KRYPTON lamps are miles ahead of ordinary light bulbs. Thanks to their krypton filling they provide up to 10% more light. Their high-quality coating ensures that the light is uniformly white and glarefree. This modern high-power light is therefore ideal for illuminating large rooms or areas used for reading or working.
>
> **For working and reading**
> Over your desk you need light that is more than just bright. The pleasant uniform light from OSRAM SUPERLUX® KRYPTON cuts down on annoying reflections on the work surface,

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[3] W.E. Thouret, R. Kaufman, and J.W. Orlando, "Energy and cost saving krypton filled incandescent lamps," *Journal of IES*, April 1975, pp. 188-197; and W.E. Thouret, H.A. Anderson, and R. Kaufman, "Krypton Filled Large Incandescent Lamps," *Illuminating Engineering*, April 1970, pp.231-240.

the computer or any other reflective material. Bright light is important if you want to relax with a book without straining your eyes. Many fittings however restrict you to a relatively low wattage. This is where OSRAM SUPERLUX® KRYPTON can help, because it provides considerably more light than an ordinary light bulb from the same wattage.

Cost Effectiveness of Krypton Lamps

NEMA's assertion that krypton is not cost effective stems from underestimating electricity rates, underestimating technical efficiency potential, and overestimating incremental cost for the amount of krypton needed. Average California residential electricity rates currently quoted by the Energy Information Administration range from 11.45 to 11.98 cents/kwh (www.eia.doe.gov/cneaf/electricity/epm/table5_6_b.html). For this analysis, we use 11.5 cents/kwh, compared to NEMA's estimate of 11 cents/kwh.

Using this electricity price yields per-lamp savings estimates of $0.575 for replacing a conventional 60 watt lamp with a 55 watt krypton model of identical light output and lifetime. The corresponding value for replacing a conventional 40 watt lamp with a 36 watt krypton model is $0.46. Replacing a conventional 100 watt lamp with a 92 watt krypton model yields savings of $0.69. These savings are two to three times our high end estimate of incremental cost at retail for moving to krypton technology. The savings are five to eight times our low end estimate of incremental cost at retail.

Moreover, the inclusion of krypton gas in incandescent lamps would allow manufacturers and retailers to earn more profit per lamp sold, while still reducing consumers' total cost of ownership (see Figure 3). The extra amount consumers pay for lamps would be more than offset by reductions in the cost of operating them. This implies very short paybacks for the resulting energy savings and a highly cost-effective addition of energy savings to California's mix.

The above calculations do not include other approaches manufacturers may wish to consider over the long term include switching to a lamp size and shape distinctive from the typical A-19 lamp. Philips employed this approach very successfully with its Halogena models. Beyond the branding benefits, one other key advantage emerges: smaller bulbs require less fill gas, reducing the incremental cost even further. Durotest's researchers were able to reduce lamp volume by 23% by moving to krypton fill gas. Bulb sizes are often dictated today by a need to keep the physical surface of the lamp far enough away from the filament to ensure temperatures do not exceed safe levels. Because krypton gas is a more effective insulator than argon, krypton lamps can be somewhat smaller without exceeding their safety thresholds.

Figure 3 - Lamp price and profit estimates